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Monitoring of the hydrodynamic instabilities in conical spouted beds by recurrence plot analysis of pressure fluctuations and acoustic emission signals

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Monitoring of Liquid Sprayed Conical Spouted Beds by Recurrence Plots

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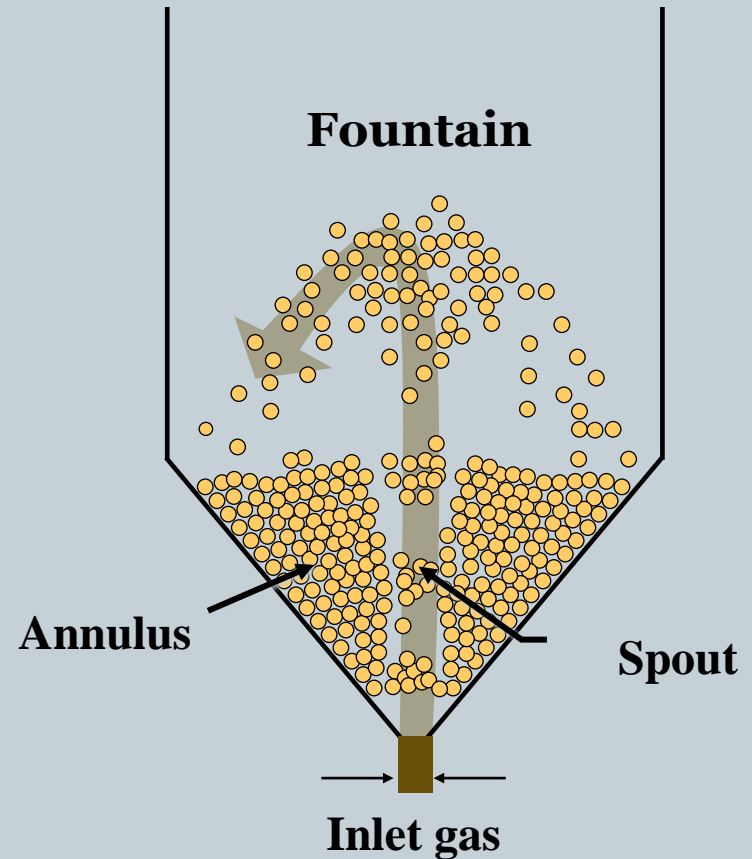
Fairmont Le Chateau Montebello

Quebec, Canada

Spouted Beds

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- Gas-solid contactors which provide intense contact for large and dense particles.
- In a conical spouted bed, the cylindrical section merely acts as freeboard and the static bed height does not exceed the conical section.
- The main advantages are short gas residence times with narrow distribution and better operating stability.



Applications of Spouted Beds

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Chemical Processes

- ✓ Chemical vapor deposition
- ✓ Biomass, waste and scarp tire pyrolysis
- ✓ Chlorination of metal oxides
- ✓ Combustion or gasification of coal

Physical Processes

- ✓ Drying of beans, slurries and pastes
- ✓ Granulation of particles
- ✓ Coating of particle such as nuclear fuel coating process

Liquid Spraying Conical Spouted Beds

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- Coating and granulation processes usually involve the presence of a liquid in the bed.
- Bed malfunctioning would happen due to stickiness or adhesiveness of the bed material.

Causes of
particle
adhesions

- 1) Addition of solution or sticky material
- 2) Chemical reaction
- 3) Particles electrical charge
- 4) High temperature

- Therefore, monitoring of spouted bed parameters is important since the performance of these beds strongly depends on their hydrodynamics

Detection Methods

5

Measuring
Techniques

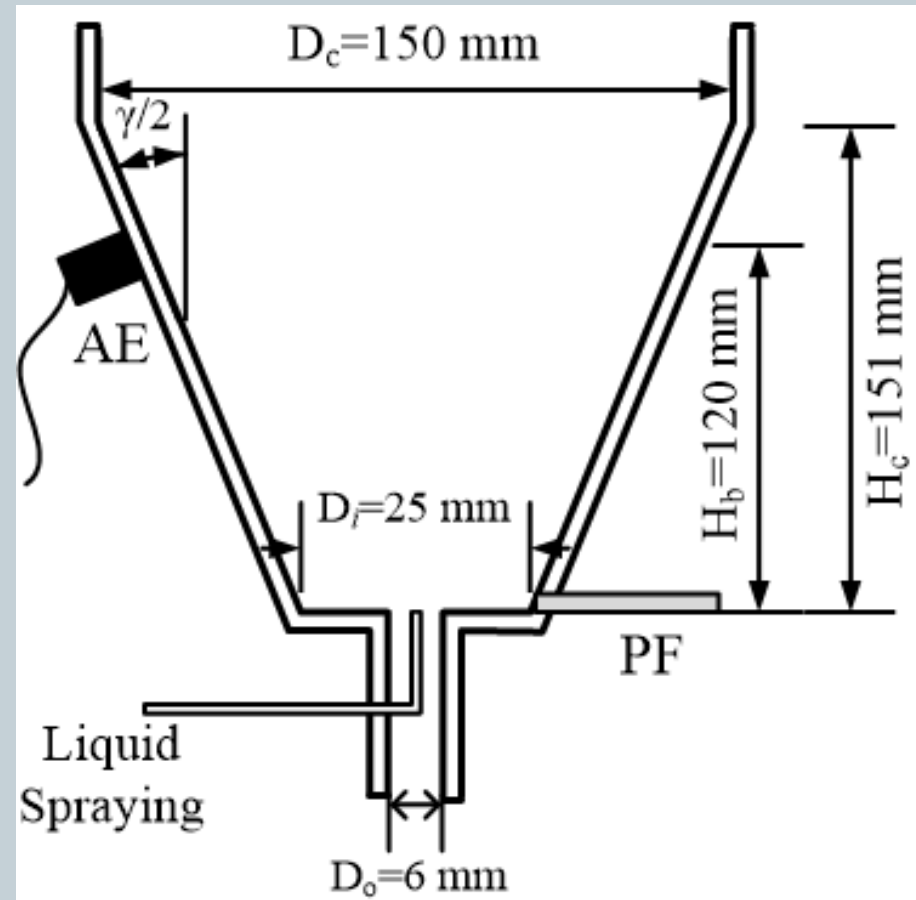
Intrusive: **Pressure Fluctuations (PFs):** easily measurable, include the effect of various phenomena in the spouted bed, such as individual and bulk movement of particles and formation and movement of agglomerates

Non-Intrusive: **Acoustic Emission (AE):** low cost, reliable measurement technique, applicable to a wide range of process conditions (high pressure and temperature, corrosive)

Experiments

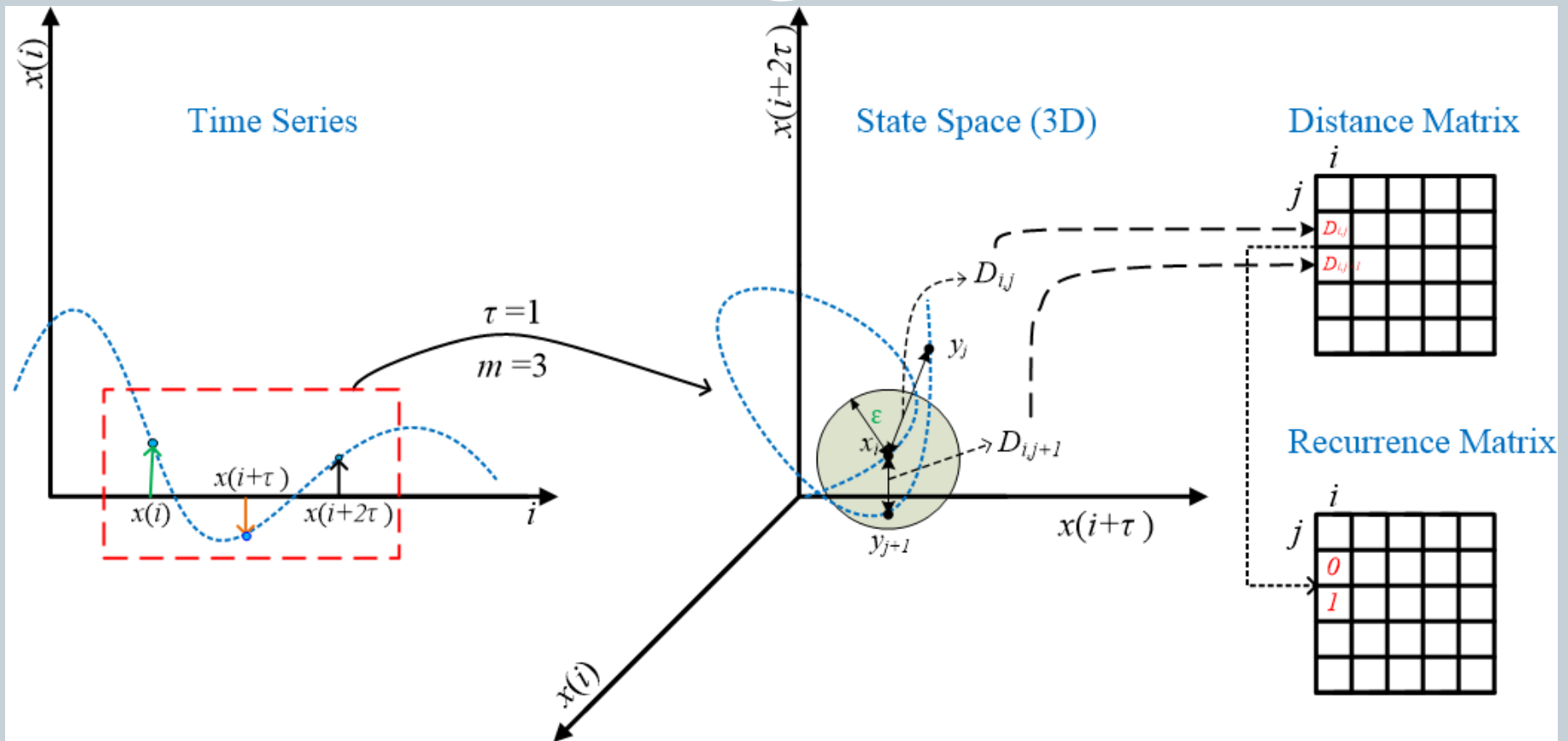
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- Full conical spouted bed
- Sugar particles ($720\ \mu\text{m}$)
- Water was sprayed in intervals until de-spouting was observed
- Continuous measuring of PFs and AE signals
- Half column conical spouted bed
- Photography of half bed to visualize of flow patterns



Construction of RP

7



Conventional RP or thresholded RP (TRP)

Analysis Methods

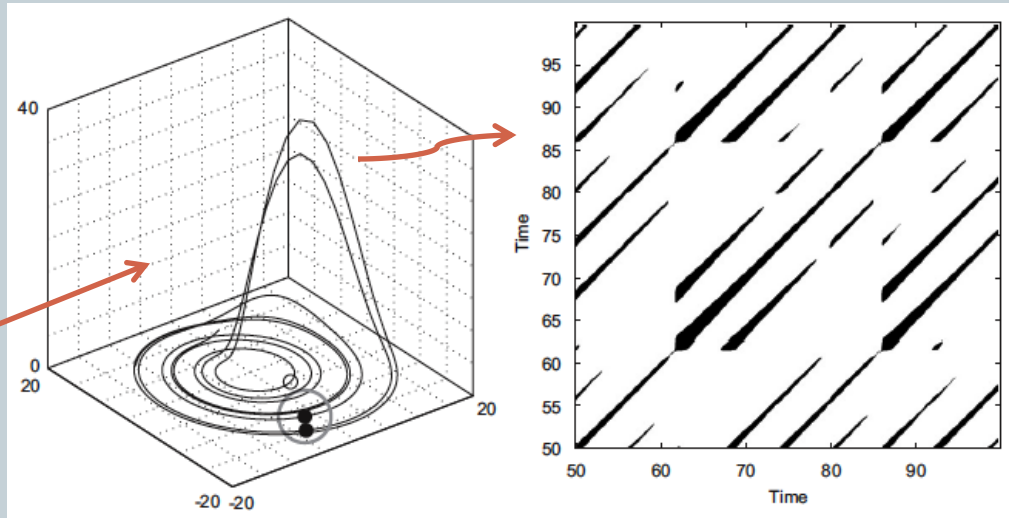
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○ Recurrence Plot (RP) Definition

➤ A two-dimensional square matrix

$$R_{i,j}(\varepsilon) = \Theta(\varepsilon - \|\vec{x}_i - \vec{x}_j\|) \quad i, j = 1, \dots, N$$

$$R_{i,j} = \begin{cases} 1 : \vec{x}_i \approx \vec{x}_j \\ 0 : \vec{x}_i \neq \vec{x}_j \end{cases} \quad i, j = 1, \dots, N$$

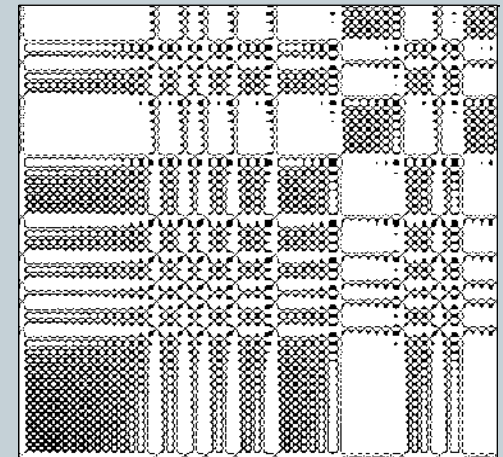
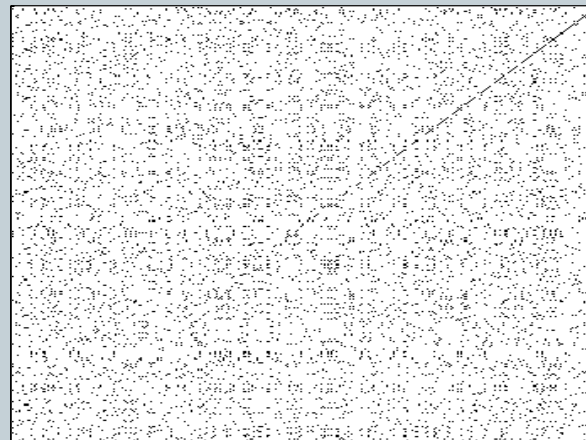
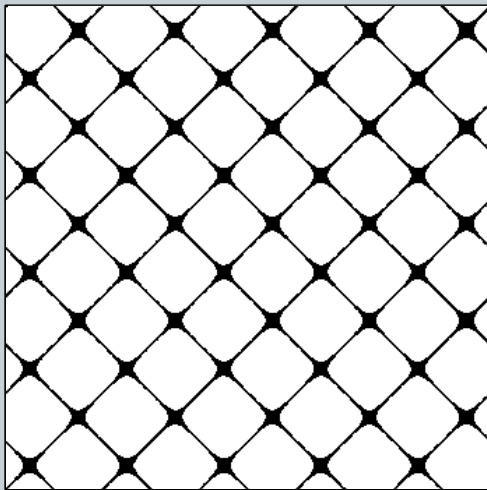
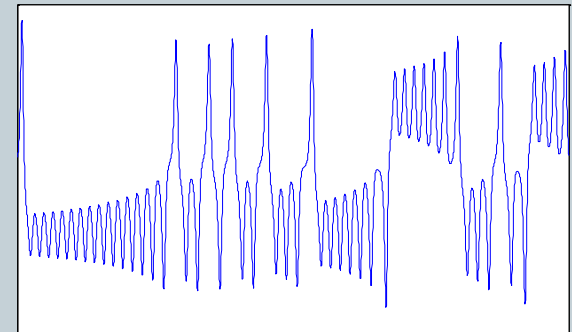
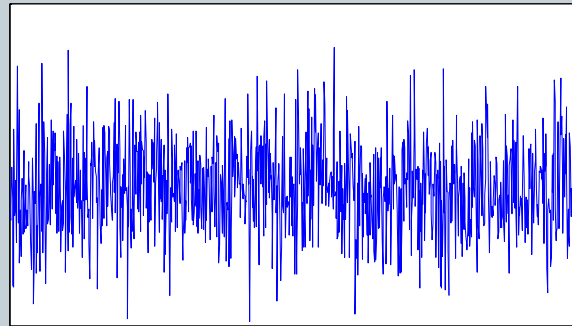
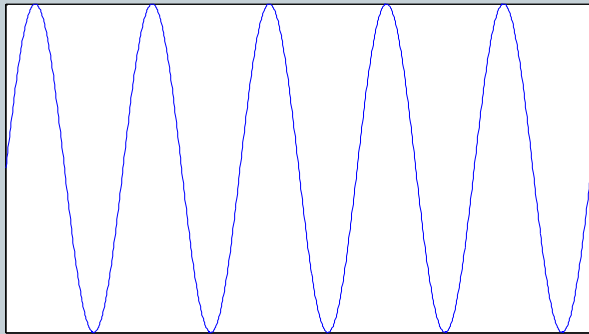


State Space

Recurrence
Plot

RPs of Different Systems

9



Periodic System

Random System

Lorenz System

Unthresholded RP (UTRP)

10

- This type of recurrence plot is defined based on the distance matrix, $D_{i,j} = \|\vec{x}_i - \vec{x}_j\|$.
- UTRPs generally appear as color maps and eliminate the need to determine radius threshold (ε).
- UTRP patterns contain more information than the TRP but this type of RP is difficult to quantify.
- The UTRPs are used for visual inspection of RPs whereas the TRPs were applied for recurrence quantification analysis

Recurrence Quantification Analysis (RQA)

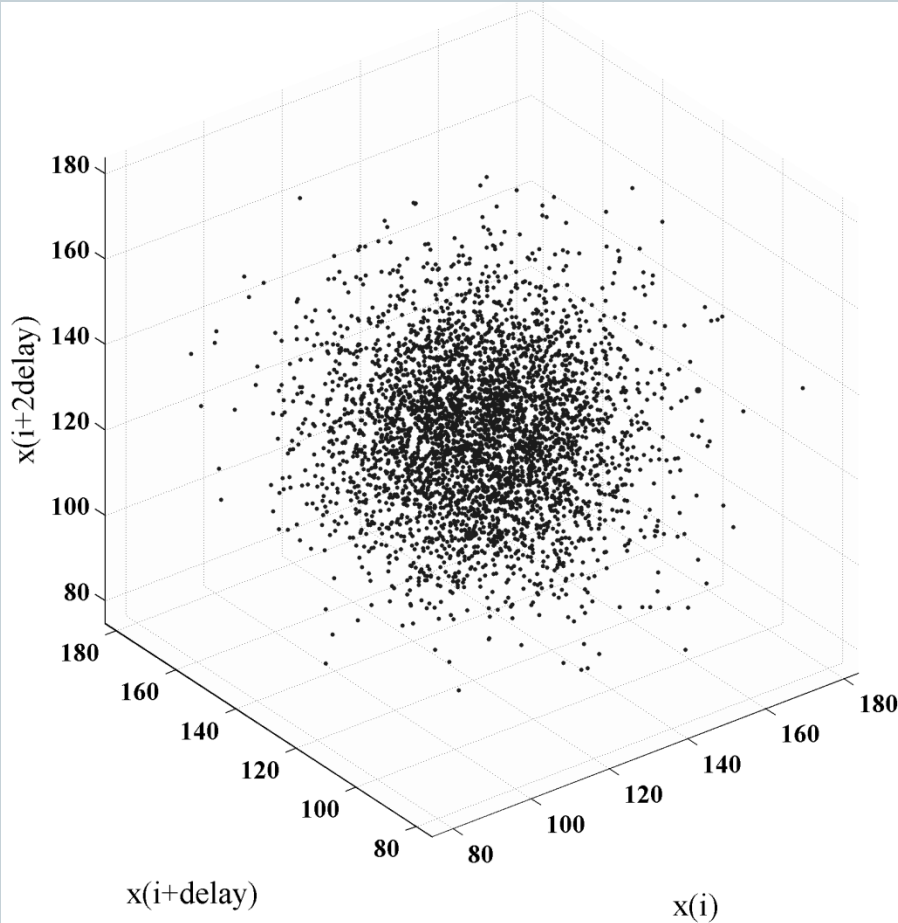
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- Several recurrence variables have been defined as complexity measures based on diagonal line structuring in TRPs.
- The **length of the longest diagonal line** in the TRP, excluding the main diagonal line, is a very important recurrence variable.
- Its inverse is related to the Lyapunov exponents.
- Positive Lyapunov exponents hint the rate at which trajectories diverge.

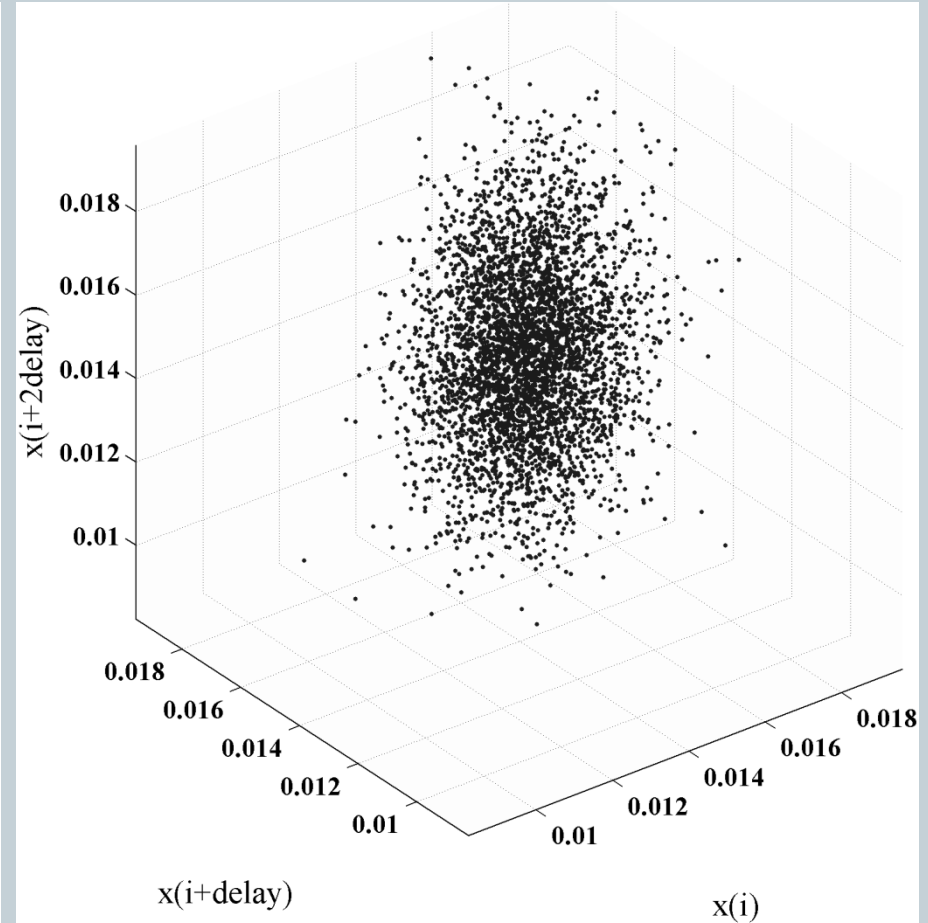
Reconstructed Attractors

12

PFs



AE

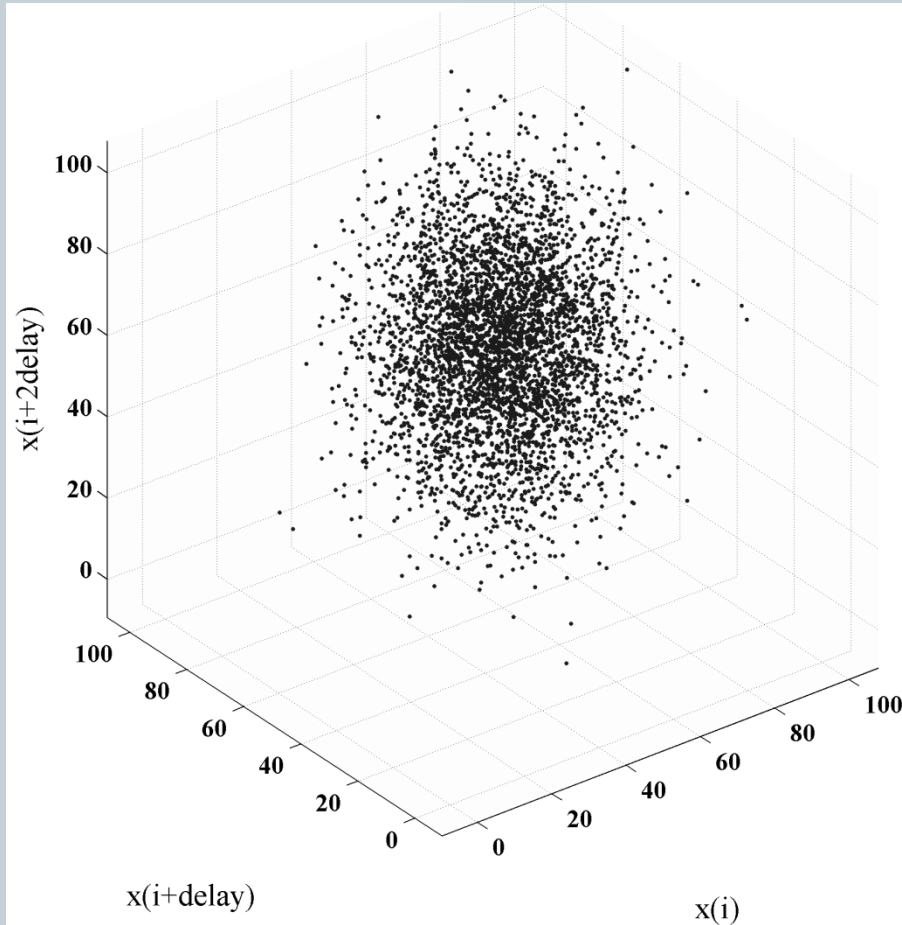


Dry Bed

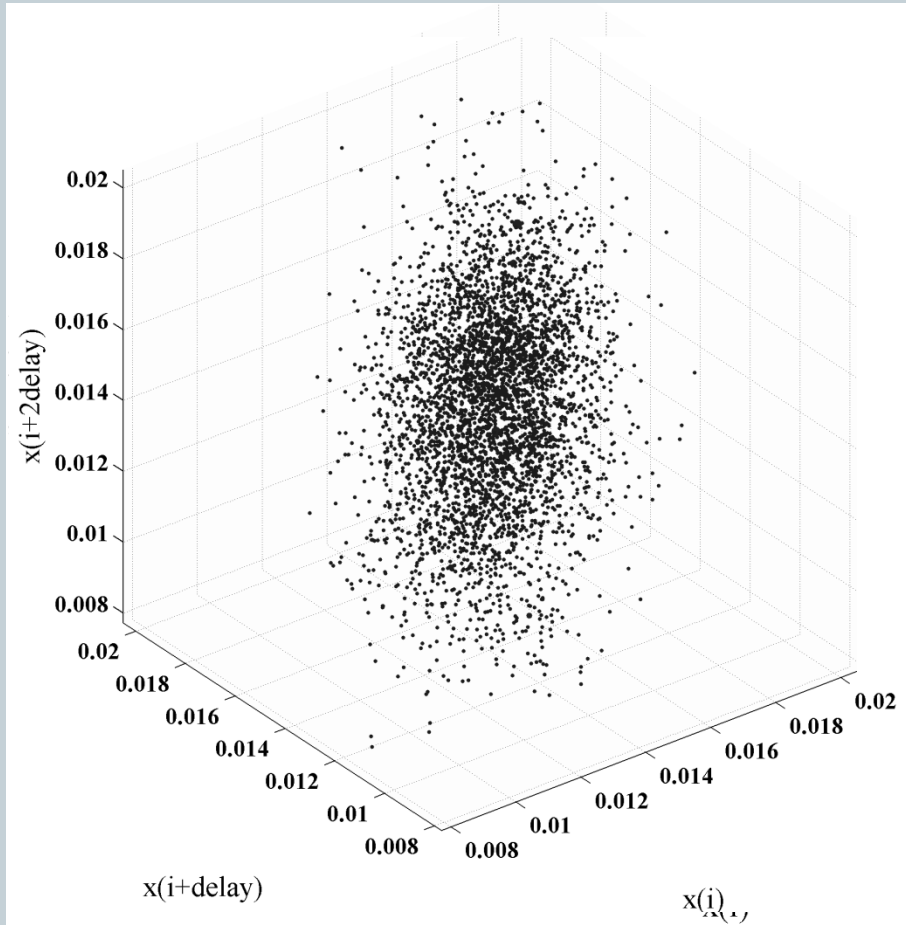
Reconstructed Attractors

13

PFs



AE



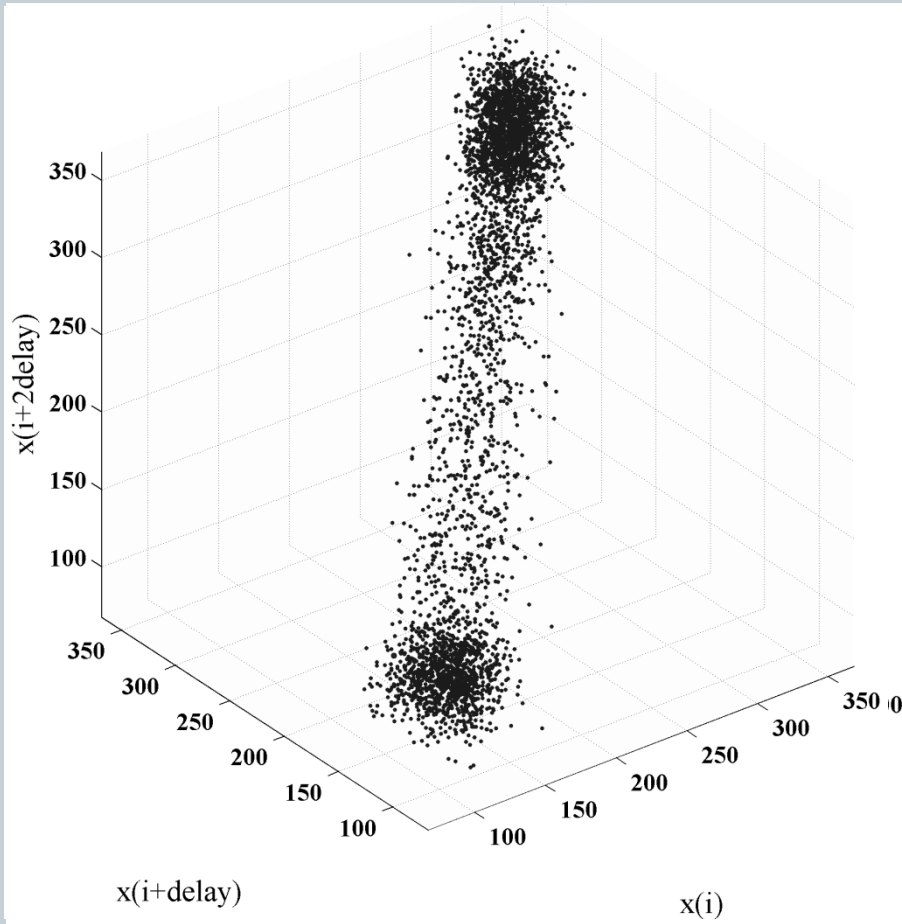
after 0.5 mL water injection

Monitoring of Liquid Sprayed Conical Spouted Beds by Recurrence Plots

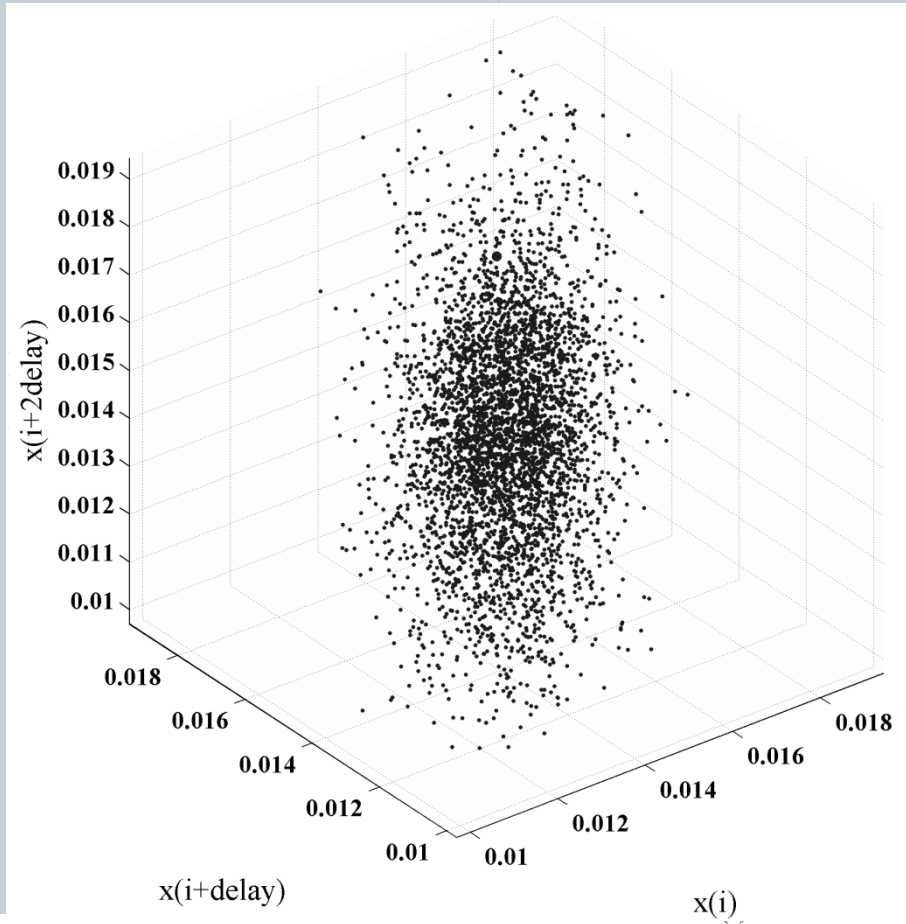
Reconstructed Attractors

14

PFs



AE

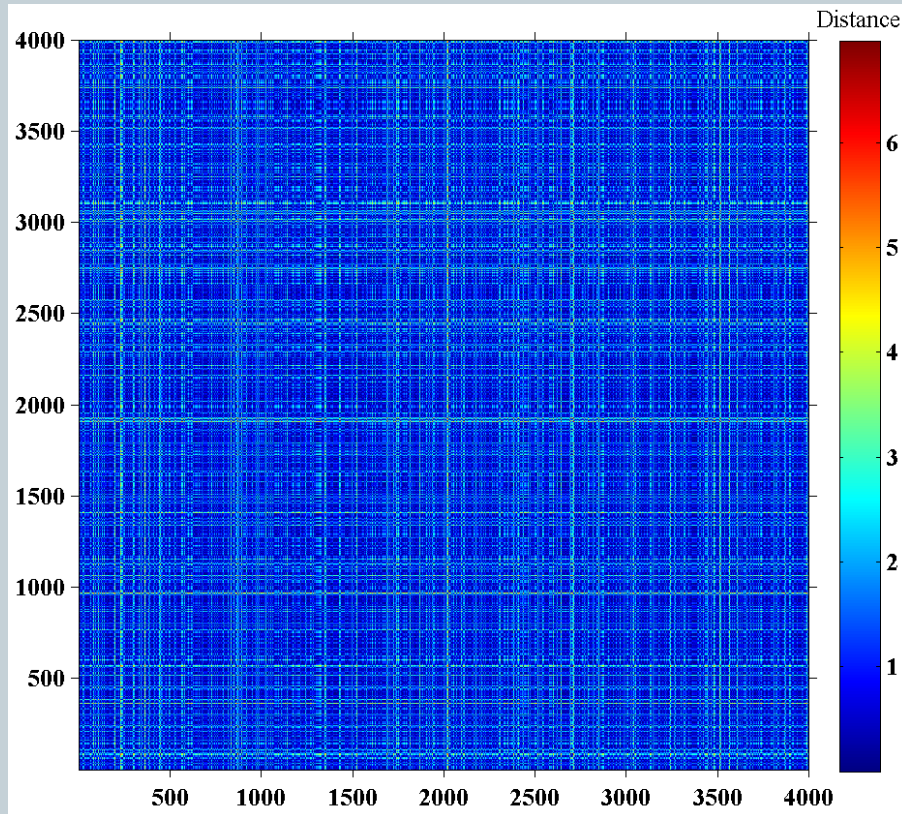


after 1.5 mL water injection

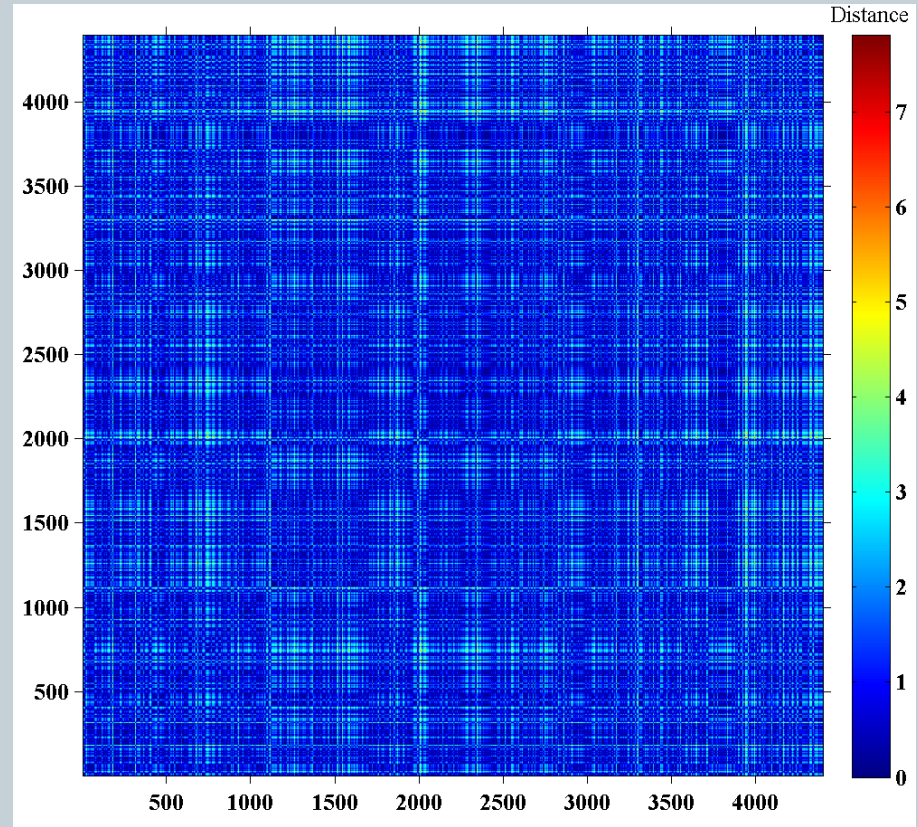
UTRPs

15

PFs



AE

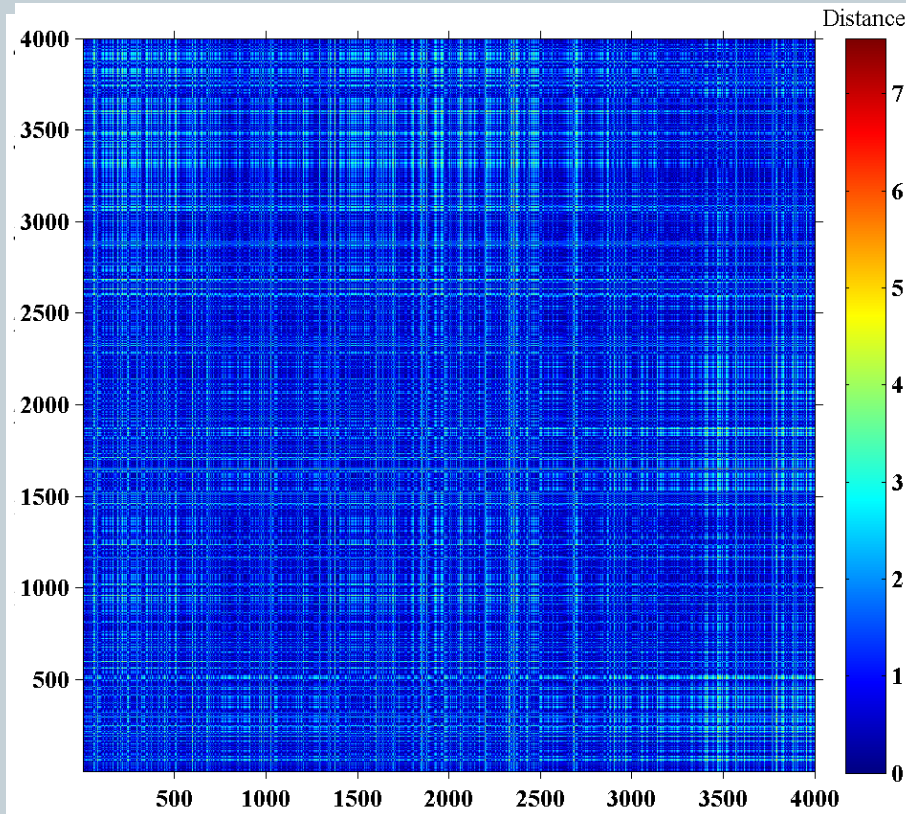


Dry Bed

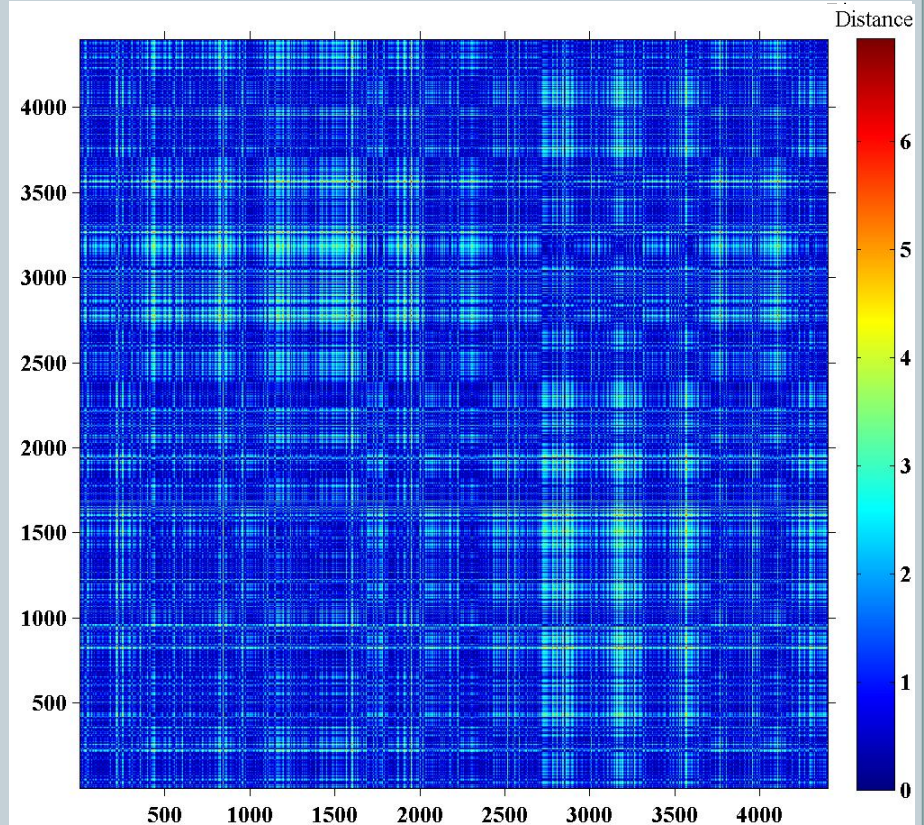
UTRPs

16

PFs



AE

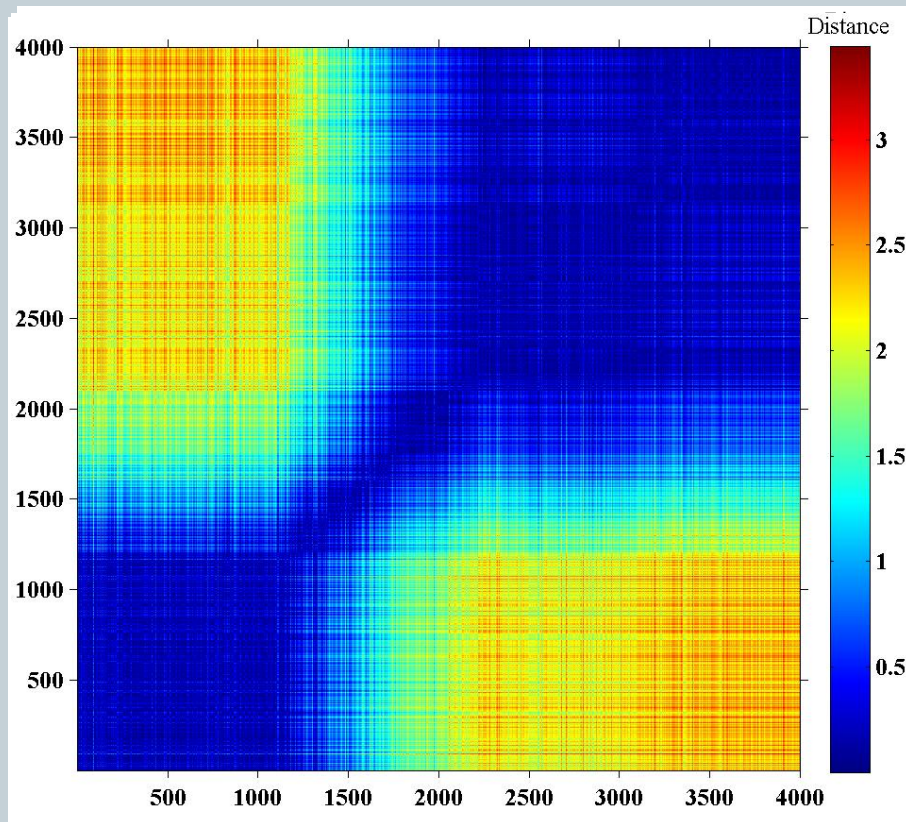


after 0.5 mL water injection

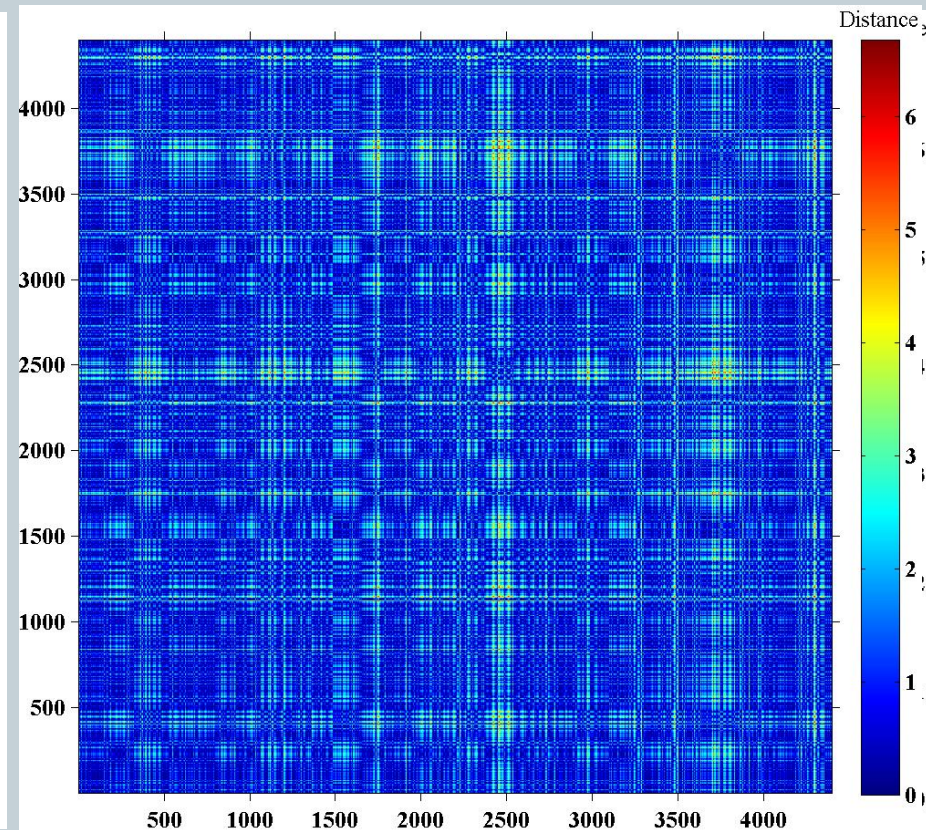
UTRPs

17

PFs



AE

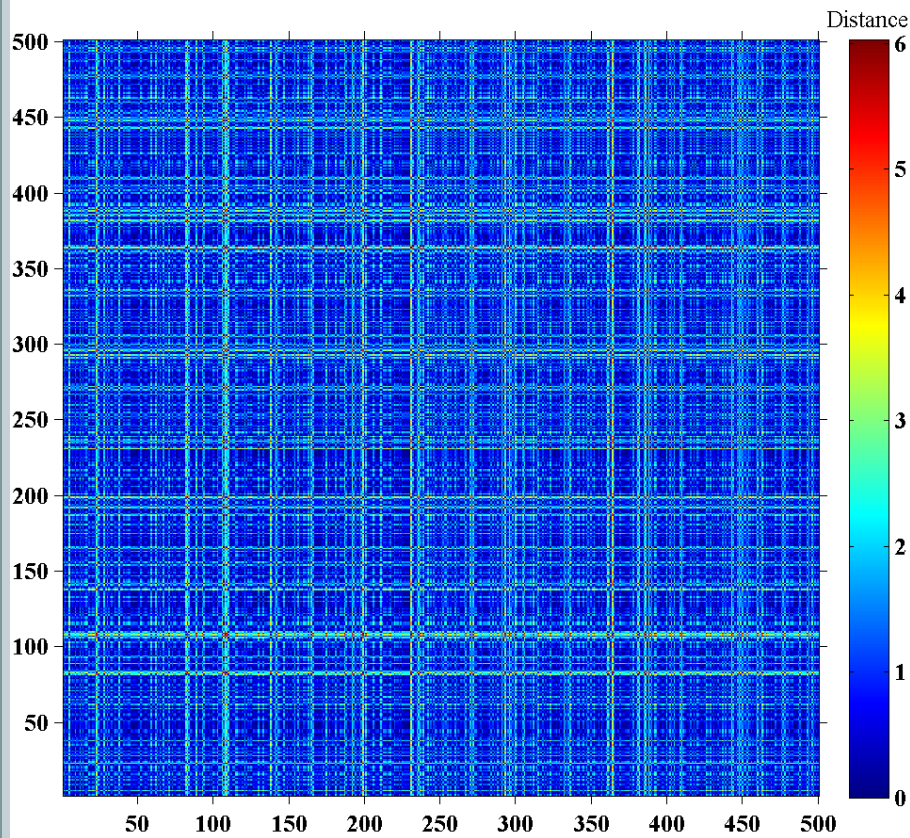


after 1.5 mL water injection

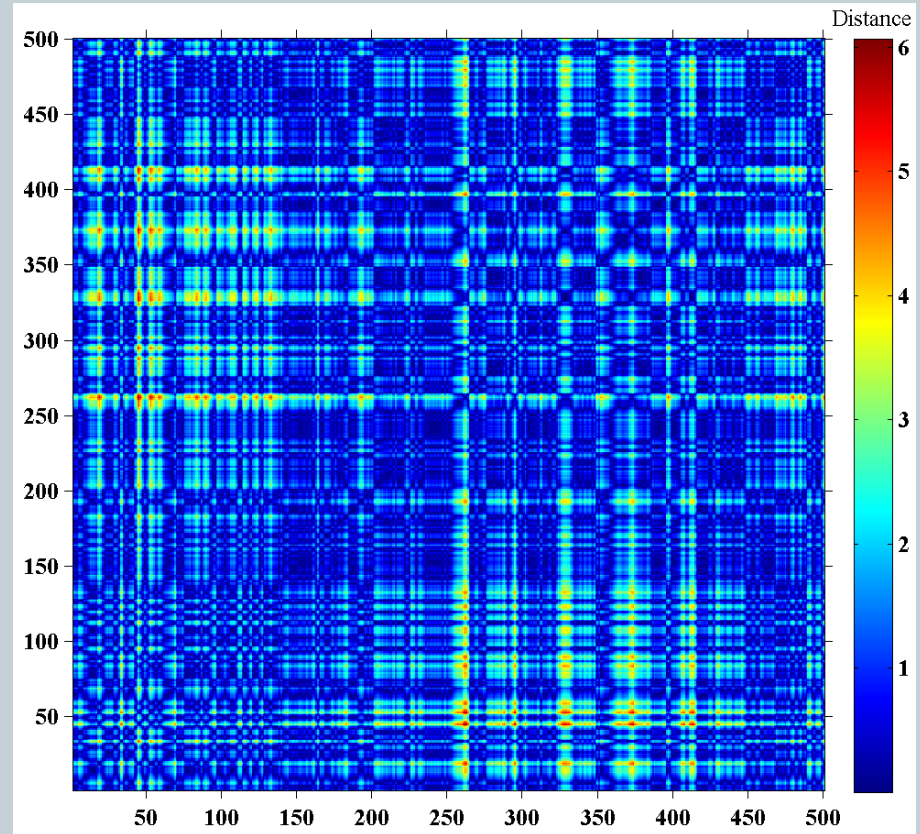
Zoom of UTRPs

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PFs



AE

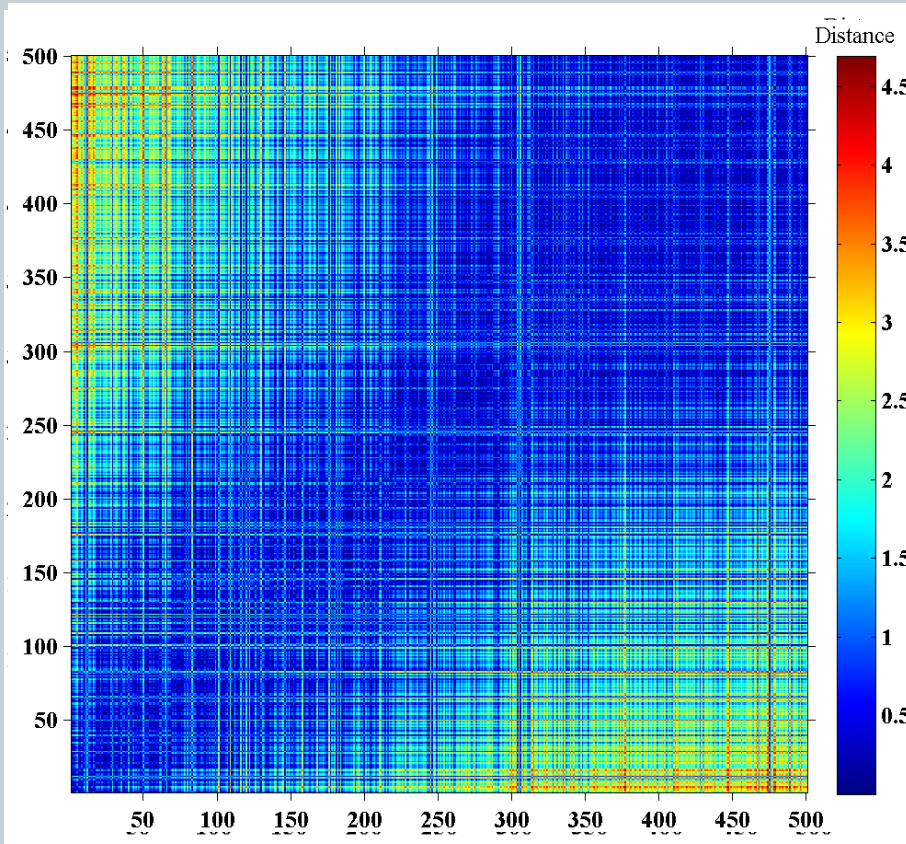


Dry Bed

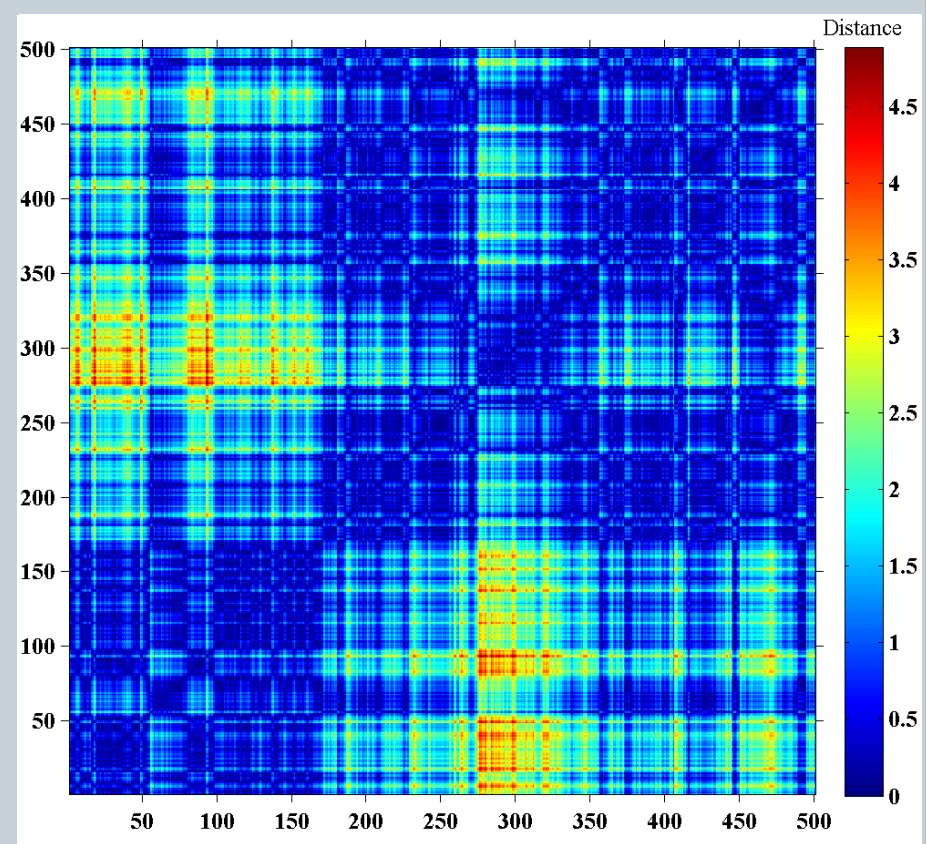
Zoom of UTRPs

19

PFs



AE

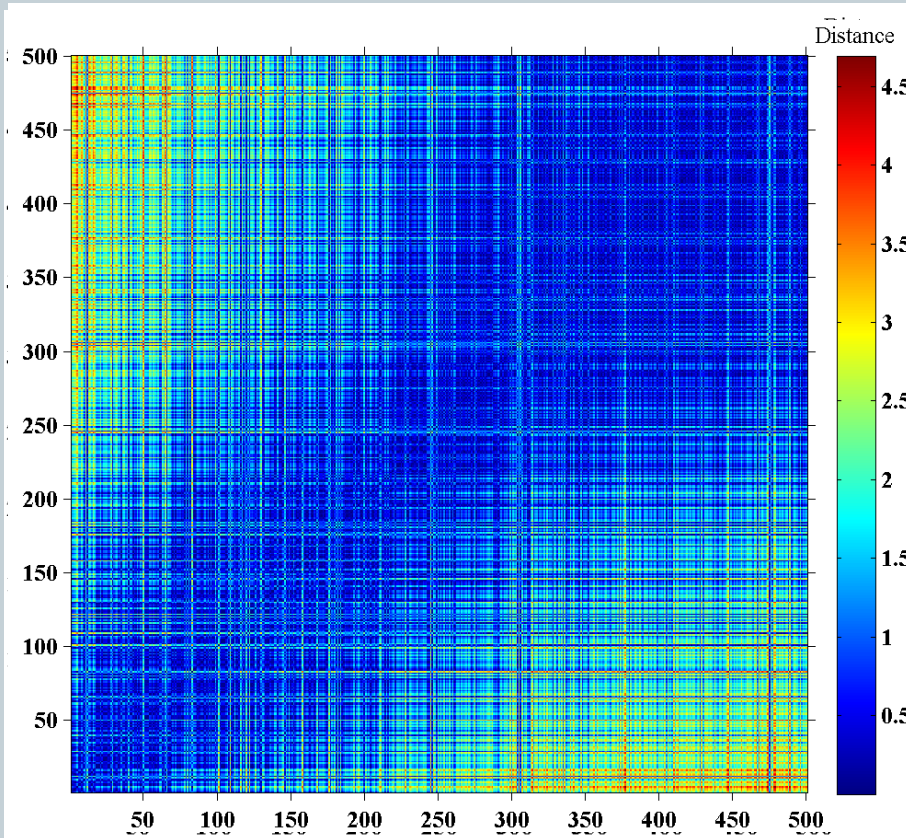


after 0.5 mL water injection

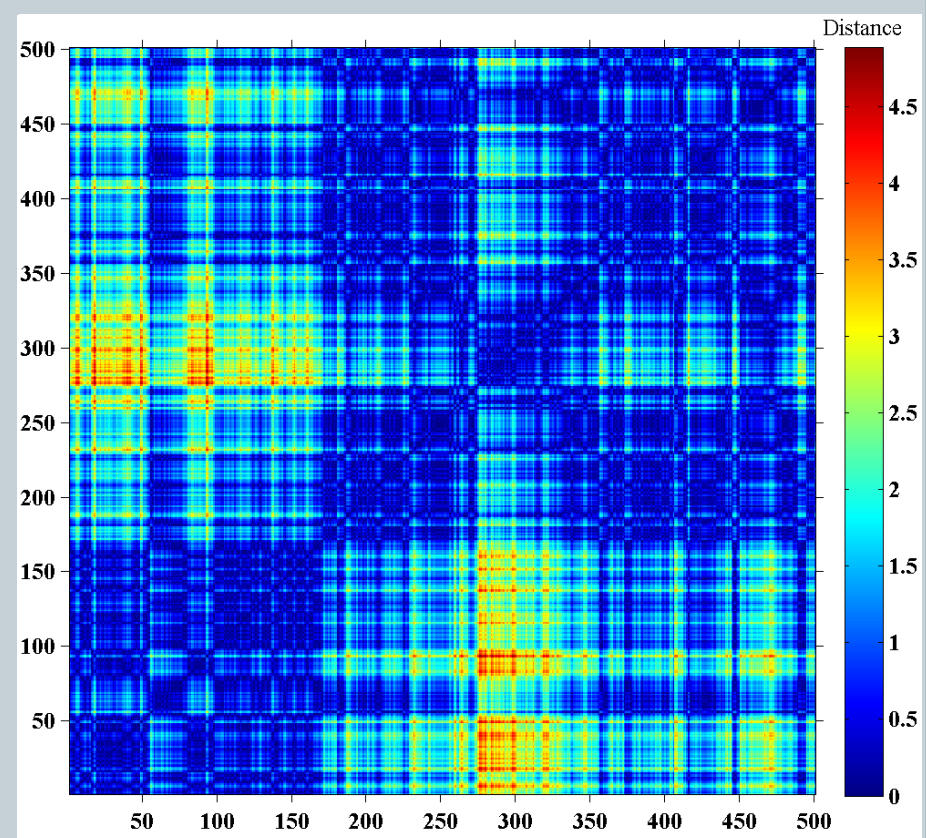
Zoom of UTRPs

20

PFs



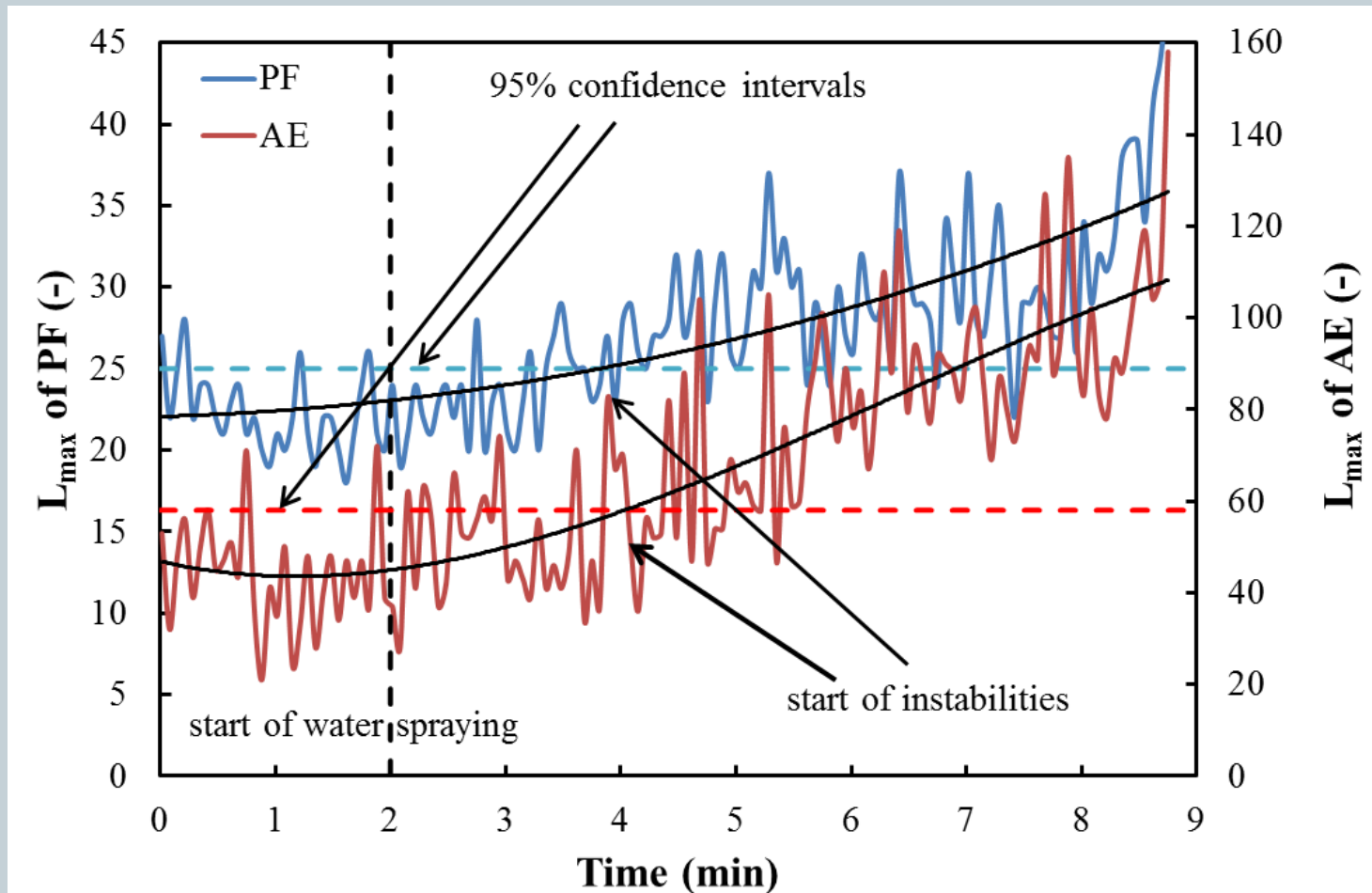
AE



after 1.5 mL water injection

Maximal length of diagonal line of the TRPs

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Conclusions

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- The recurrence plot method can be used as a powerful technique for monitoring the hydrodynamics of conical spouted beds.
- The reconstructed phase space trajectories of both PFs and AE signals approach to a slim and elongated pattern by injection of water into the bed.
- Changes in the visual appearance of the UTRPs of AE signals are more obvious, even without any quantification analysis.
- Examination of maximum length of diagonal lines of thresholded RPs (TRPs) showed that PFs and AE signals of the bed approach that of a periodic time series with injection of water.
- Hydrodynamic behavior of bulk movement and agglomerates is more deterministic than movement of single particles

Thank you for your attention